Chapter 14

Orthopaedics

- **Triage**

The general categories of care (ie, immediate, delayed, expectant, minimal, and urgent) apply to civilian pediatric casualties in a mass casualty situation. In a combat setting, it is possible that a traditionally defined pediatric patient (< 18 years old) may be an enemy combatant and in a special category that places medical personnel at risk. Although these patients are treated the same as "friendly casualties," it is mandatory to carefully screen for ordnance and weapons before moving the casualty to patient care areas.

- Resource constraints
    - Utilization: it is imperative to constantly reassess resources to conserve necessary equipment and personnel
    - Standard of care: treating pediatric orthopaedic problems in theater may be different than in a noncombat environment
        - Resources in roles 1–3 military medical treatment facilities are focused on adult orthopaedics; equipment tailored to pediatric sizes and specific problems may not be available
        - Weather, sanitation, and ease of transport may alter treatment; for instance, external fixation of closed long-bone fractures may be elected over open fixation to obviate infection, or external fixation may be more practical than closed treatment in a heavy cast
        - Medical providers should familiarize themselves with local medical care resources for follow-on treatment; the treatment regimen chosen must be compatible with available local civilian resources

        - General knowledge of the indigenous cultural views on health, gender, and specific conditions (eg, amputations and congenital deformities) is helpful in directing care for pediatric civilian casualties; chaperones may be necessary when examining a patient's unclothed extremity
  - Disposition. Local pediatric civilian patients will typically stay in country and are not usually evacuated to a higher level of care (occasionally a local patient is transferred). The judgment of when to end care in the military system may be difficult and will usually be resource and safety dependent. Liaison with local resources and avenues to the International Committee of the Red Cross should be investigated
  - Outcomes. Medical personnel delivering humanitarian care should be aware of, but not disappointed by, the limitations in orthopaedic care. Short-term intervention may have limited impact and cultural norms may affect efforts to improve outcome
- **Epidemiology**
  - Types of orthopaedic care
    - Trauma. Children are subjected to the same mechanisms of injury as war fighters. In the past two decades, the leading etiologies of pediatric orthopaedic trauma seen in deployed military facilities are:
      - Blast injury (ie, direct contact with an explosive device)
      - Penetrating injury
      - Thermal injury
      - Blunt force injury
    - Congenital malformations/reconstruction. Deployed orthopaedic surgeons may be asked to evaluate and treat mild to severe congenital anomalies. Healthcare providers must use good judgment when initiating reconstructive treatment because there may be limited means for follow-up or follow-on treatment
    - Infection. Pediatric musculoskeletal infections may be caused by pathogens endemic to the geographic area of operations

- Wound infections may be caused by common environmental microorganisms
  - *Staphylococcus aureus* remains the most common cause of musculoskeletal infection throughout the world
  - *Salmonella typhi* has been reported to be the most common infecting organism in Africa
  - *Acinetobacter baumannii* is common in southwest Asia. It is found in soil and can live on open surfaces for a number of days, enabling it to spread. Patients with open wounds and on ventilators are susceptible to this multiple drug-resistant organism
  - *Klebsiella pneumoniae*, an organism that lives in water, is typically acquired in a hospital setting and is often associated with people with poor nutrition and those with slightly depressed immune systems
  - *Pseudomonas aeruginosa* thrives in moist environments and is a threat to patients with several kinds of injuries, including burns. *Pseudomonas* and *Staphylococcus epidermidis* are the most common causative agents of infection in extramedullary implants in local hospitals in Iraq
  - Clostridia are gram-positive, anaerobic, spore-forming bacilli found in high density in cultivated rich soil. *Clostridium perfringens* is the most common cause of gas gangrene and food poisoning. *Clostridium difficile* is responsible for pseudomembranous colitis after long-term antibiotic usage
- Osteomyelitis and septic joints can be hematogenous in origin or result from direct inoculation. The causative organisms are those found in the particular environment. The first principle of treatment is to evacuate purulent material when it is entrapped. Eradication of osteomyelitis or a septic joint will require long-term antibiotic therapy

- Difference in levels of trauma. Although common pediatric orthopaedic trauma may present to the military medical facility, most cases will be more complex. In the civilian and military settings in the continental United States, the receiving facility often provides emergency care and transports the patient to a higher-level facility for definitive care. In theater, the major orthopaedic care for local civilians will occur at the military facility, followed by transportation to a lower-level facility

- **Amputations**
  - Children sustain amputations from the same mechanisms of injury as war fighters
    - Exsanguination is the immediate concern
    - Explosive munitions with penetration and concussive blast effects create a large zone of injury with extensive contamination that may affect the level of final amputation
  - Indications for amputation
    - Partial or complete traumatic amputation
    - Irreparable vascular injury or failed vascular repair with an ischemic limb
    - Life-threatening sepsis due to local infection, including clostridial myonecrosis
    - Severe soft tissue or bone injury beyond functional recovery
  - Principles of amputation
    - Amputations should be done at the **lowest level of viable tissue** (in contrast with traditional amputation levels; eg, below the knee, above the knee, etc) to preserve as much limb as possible; a longer residual limb is most desirable for prosthetic fitting and will serve the amputee best if prosthetic fitting is not possible
    - Open length-preserving amputation has two stages:
      - Initial: the bone is completed at the lowest possible level; the residual limb is left open
      - Reconstructive: this involves the process of healing to reach optimum function and prosthetic fitting; civilian pediatric amputees will undergo this phase in country, unlike military patients who will be evacuated out of the combat zone for reconstruction in a stable environment

    - All viable skin and soft tissue distal to the amputated bone should be preserved for future wound closure. These "flaps of opportunity" can be used to add length to the residual limb regardless of irregularity
- Amputation technique
    - Apply tourniquet. It is necessary to limit blood loss and preserve volume in trauma patients. There is very little literature on the use of tourniquets in the pediatric population (see Further Reading at the end of this chapter). General guidelines are as follows:
        - Place the tourniquet on the most proximal portion of the limb
        - Use the widest cuff possible suitable for the limb, location, and procedure
        - Use a specifically designed limb protection sleeve for the cuff, if available. If not, use two layers of tubular stockinette, slightly stretched but not tight
        - Apply the tourniquet snugly over the sleeve
        - Determine the occlusion pressure and set the tourniquet pressure to 50 mmHg above that (average is 175 mmHg)
        - Exsanguinate by elastic bandage or gravity, as appropriate for the case
        - If bleeding persists after cuff inflation, increase the cuff pressure in increments of 25 mmHg until it stops
        - Minimize tourniquet time (no more than 2 h without 15 min deflation time)
        - Remove the cuff and sleeve as soon as possible after the tourniquet is deflated
    - Prepare entire extremity
    - Excise nonviable bone and soft tissue that has been devascularized
    - Ligate major arteries and veins
    - Locate major nerves, provide gentle traction, and transect proximal to the level of amputated bone; ligate major nerves
    - Preserve muscle flaps, but do not suture
    - Full debridement of a blast injury may require extending

incisions longitudinally to remove contamination along fascial planes

- Differences in managing local amputees
  - Definitive care will be provided in theater. Following the principles of the Red Cross surgeons working in relatively stable environments, the local civilian pediatric patient will undergo delayed primary closure when the wound is clean. Skin retraction of open residual limbs should be prevented, using skin traction until closure is possible. Skin traction may be accomplished through a classic technique of benzoin-secured stockinette and 1–2 lb of weight (Figure 14-1). In select situations, skin retraction can be prevented by placing large, loose trauma sutures with bolsters or vessel loops and skin staples at the wound margins. Preserving viable skin flaps, even if they are irregular, aids in closure and is preferable to skin grafting

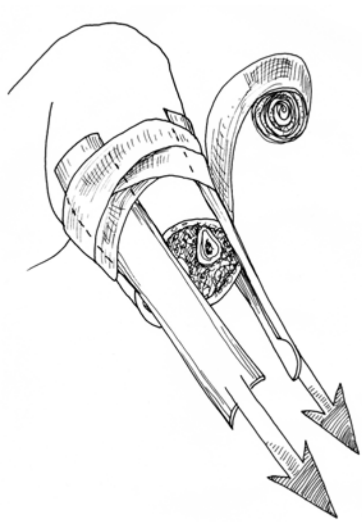

Figure 14-1. Cut away view of stockinette skin traction.

  - Acceptance of the amputee patient and the type of prosthesis may be different in the local culture. Existing local resources for prosthetic fitting may be limited.

When applicable, early prosthetic fitting, especially in upper-extremity amputations, promotes best functional use of the prosthesis. Frequent prosthetic changes are expected

- Because of growth and the quantity of young healing bone, various long-term problems may arise, especially in below-the-knee amputations, such as:
  - Anterior bowing associated with the distal element pointing medially; varus bowing with the distal element pointing medially
  - Heterotopic bone formation, requiring revision
  - The fibula may outgrow the tibia, resulting in the formation of bursa overlying the fibula and prominent bone spicules projecting beneath the skin
  - These problems can be prevented or controlled by synostosis of the distal fibula and tibia, which results in an end-bearing residual limb (this procedure should **not** be performed until the soft tissues have fully healed)

- **Fractures**
  - Evaluating fractures
    - Obtain history, perform a physical examination to fully assess injuries, and establish vascular and neurologic status of the extremities
    - Obtain radiographs of the adjacent joints (above and below the fracture in the case of a long-bone fracture), with images in two planes
    - Examine and cover open wounds, preferably with a sterile dressing
    - Splint the involved extremity, including the joints above and below, for a long-bone fracture
    - Fracture reduction should be done with adequate anesthesia or analgesia
    - After reduction and application of a cast or external fixator, reevaluate vascular status and nerve function of the limb
    - Children's fractures remodel 1°/mo for the first 24 months
  - Open fractures

    - Open fractures sustained in a combat area are produced by small arms (bullets) and explosive munitions (improvised explosive devices, mortars, artillery, land mines, grenades, or bombs)
    - The most common battlefield injury is multiple fragment wounds that involve only the soft tissue
    - Open fractures caused by weapons of war are more severe than those seen in a noncombat setting
    - Initial treatment for open fractures
        - Evaluate the wound while the patient is under anesthesia
        - Surgically incise the skin and fascia to inspect the soft tissues and fracture site
        - Excise devitalized tissue or debris
        - Copiously lavage with a physiological solution to decontaminate and remove debris, dead tissue, or hematoma
        - All wounds should initially be left open and closed at a later date
        - Negative-pressure (wound vac) wound dressings may be a useful adjunct, especially for more extensive wounds
        - Administer systemic antibiotics appropriate for the wound
        - If a skin defect is present, perform coverage as a second, staged, operative procedure only after the wound is clean and free of necrotic tissue
        - Coverage procedures should be planned and performed in a stable environment
- Long-bone fractures
    - General
        - Internal fixation of pediatric fractures in theater is rarely, if ever, indicated because of operative conditions and potential for infection
        - Based on the patient's size and available equipment, external fixation may be desirable for stabilizing long-bone fractures in theater. Appropriately sized fixators may not be available; the "pins in plaster" technique may be used to maintain length

- ▹ Casting remains an acceptable treatment option, provided alignment can be maintained; skeletal traction is also a useful means to care for some fractures
- ▹ See Figure 14-2 for fracture classification

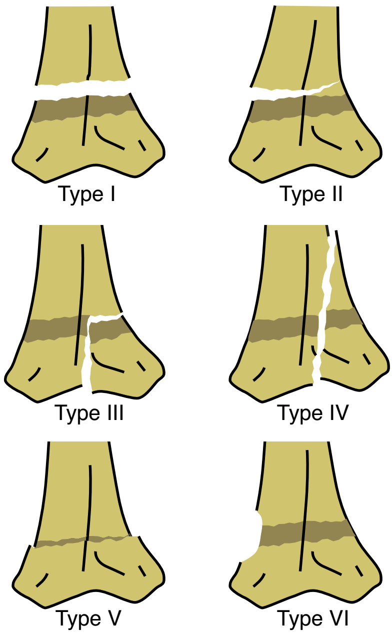

Figure 14-2. Salter-Harris classification of fractures involving the growth plate. Type I: transverse fracture through the physis. Type II: fracture through the physis and metaphysis. Type III: fracture through the physis and epiphysis. Type IV: fracture through all three (physis, metaphysis, and epiphysis). Type V: physeal compression fracture. Type VI: peripheral physeal injury.

- Upper extremity fractures
  - ▹ Proximal humerus fractures. The majority of proximal humerus fractures in the pediatric age group are treated conservatively with a sling and swathe for roughly 2 weeks. Gradual return to normal function is allowed once pain subsides
  - ▹ Midshaft humerus fractures. Use a coaptation splint

with a sling and swathe for comfort; this may be changed to a Sarmiento-type brace at 2 weeks (if available) instead of definitive treatment in long-arm cast

- Supracondylar humerus fractures
  - Significantly displaced fractures (Gartland types 2 and 3) require closed reduction and percutaneous pinning; crossed medial and lateral pins (rather than two or more divergent lateral pins) are adequate
  - Place the extremity in a long-arm cast for 3 weeks and consider a bivalving cast if swelling is present; remove pins at 3 weeks and begin activities as tolerated
  - Avoid immobilization in more than 90° of elbow flexion; this may lead to ischemic contracture
  - Type 2 fractures can sometimes be reduced and held without pinning with a long-arm cast (see precautions above)
- Lateral condyle fractures
  - These are often difficult to diagnose in the younger population; when in doubt, use an arthrogram to diagnose
  - Open reduction is indicated if the fracture enters the joint and there are more than 2–3 mm of displacement
  - Use a lateral approach; do not strip posterior soft tissue attachments off the fragment because blood supply enters posteriorly
  - A headlight is often useful
  - Reduce the fragment and pin with 2 or more Kirschner wires
  - Use a long-arm cast for 4–6 weeks, then remove pins
- Medial epicondyle fractures rarely require treatment, regardless of displacement, unless they are entrapped in the joint (in which case, open reduction and pin fixation is indicated)
- Forearm and wrist fractures
  - These may involve the radius, ulna, or both, and may occur at the distal, middle, or proximal forearm

- Remodeling potential is greatest in younger patients and in distal areas near the physis
- Expect an angular correction of approximately 1°/mo or 10°/y for 2 years
- Rotational deformities do not correct with growth; bayonet apposition of up to 1 cm is acceptable if the patient is < 8–10 years old
- If initial displacement is outside this range, fracture reduction and casting are recommended
- In general, immobilization consists of 4 weeks in a long-arm cast, followed by 2 weeks in a short-arm cast; immobilization duration varies depending on fracture healing and age
- Wrist fractures (at the distal ⅓ of the forearm) can be treated with 3–6 weeks of short-arm casting, depending on the age of the child and the fracture type

▸ Lower extremity fractures

▹ Femur fractures

- Certain current acceptable and standard treatments, such as internal fixation with plates, may not be not be reasonable in an austere environment because of risk of infection and limited equipment availability
- Treatment is typically based on the age and size of the patient and the availability of equipment in theater (Table 14-1)

Table 14-1. Guidelines for Acceptable Reduction in Femur Fractures

Age (y)	Varus/Valgus	Procurvatum/Recurvatum	Shortening
0–2	30°	30°	15 mm
2–5	15°	20°	20 mm
6–10	10°	15°	15 mm
11 and older	5°	10°	10 mm

- Birth–6 months old: casting. Use a spica cast for diaphyseal fractures and a long-leg cast for supracondylar fractures. The Pavlik harness that

is recommended in the noncombat environment may not be available
- 6–12 years old: external fixator or pins in plaster. Submuscular bridge plating is a good option in a developed healthcare system, but may not be appropriate in theater. Skeletal traction may be used where external fixation is not available or not advised (eg, while a child is confined to bed); it requires limited operating room technology
- 12 years and older: external fixator. Intramedullary nailing or bridge plating are good options in a developed healthcare system, but may not be appropriate in theater

- ▹ Tibia fractures
  - The majority of tibia fractures are treated with reduction and long-leg casting
  - Acceptable alignment: 50% apposition, < 1 cm shortening, and 5°–10° of angulation in the sagittal and coronal planes
  - A long-leg cast is applied with slight (10°–20°) ankle–plantar flexion and 45° of knee flexion
  - Time to healing is based on age; neonates heal in 2–3 weeks, children in 4–6 weeks, and adolescents in 8–12 weeks
  - External fixation and open reduction internal fixation may be used if clinically indicated (ie, in the case of severe comminution, open fractures, etc)
- ▹ Ankle fractures
  - The majority of ankle fractures are Salter-Harris–type injuries and can be treated with closed reduction and a short-leg cast
  - Displaced fractures (> 2 mm) that traverse the physis and involve the joint may require reduction and internal fixation
  - Physis may be crossed if the patient is near skeletal maturity
  - Tillaux fractures and triplane fractures are more complex ankle fractures and may need evaluation by computed tomography (CT) scan to discern

fracture pattern and displacement. Displaced Tillaux or triplane fractures are treated with open reduction and internal fixation. In an austere setting, open reduction with Kirschner wires and casting is an option

- Pelvic fractures (see Further Reading for additional guidance)
  - Overall, pelvic fractures in pediatric patients are rare
  - Usually caused by a high-energy mechanism that results in other life-threatening injuries. Comprehensive workup is indicated using advanced life support principles
  - Children have greater plasticity, thick cartilage, and more mobile joints than adults, and their vessels tend to spasm and not bleed (life-threatening hemorrhage is rare)
  - Low mortality rate (compared to adults)
  - The majority can be treated nonoperatively and have a much better prognosis than when in adults
  - Imaging
    - Radiographs (anterioposterior pelvis, inlet and outlet, Judet views)
    - CT scan is best, especially with image reconstructions
  - Treatment is based on age; fracture location, type, and stability; and concomitant injuries
    - Most are treated nonsurgically and heal uneventfully
    - Surgical indications include intraarticular acetabular or triradiate cartilage displacement of > 2 mm, and pelvic ring displacement with > 2 cm of limb length discrepancy
    - External fixation may be used for unstable fractures
  - Complications
    - Acetabular fracture or triradiate injury may lead to a dysplastic acetabulum and early degenerative changes
    - Sacroiliac joint pain

Further Reading

1. Lieberman JR, Staheli LT, Dales MC. Tourniquet pressures on pediatric patients: a clinical study. *Orthopedics*. 1997;20:1143–1147.
2. Tredwell SJ, Wilmink M, Inkpen K, McEwen JA. Pediatric tourniquets: analysis of cuff and limb interface, current practice, and guidelines for use. *J Pediatr Orthop*. 2001;21(5):671–676.
3. Holden CP, Holman J, Herman MJ. Pediatric pelvic fractures. *J Am Acad Orthop Surg*. 2007;15:172–177